# THE USE OF HEART RATE IN THE PRESCRIPTION AND EVALUATION OF EXERCISE PROGRAMS

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In Brief:

Exercise programs can be described in terms of the Type, Frequency, Duration, and Intensity of exercise. It is generally accepted that exercise 3 times per week for at least 20 minutes is the minimum needed to maintain or improve aerobic fitness. However, the appropriate exercise intensity is more difficult to specify since it varies widely both among and within individuals as a function of fitness. An easy and accurate way of determining whether an individual's exercise program is achieving the desired results is to periodically measure the heart rate response during any repeatable submaximal exercise. If there is an increase in aerobic fitness, the individual's heart rate at a given specific submaximal power output decreases, and vice versa. The feedback provided by periodic measurements of heart rates at reproducible power outputs permits the duration, frequency, and most importantly, the intensity of exercise to be adjusted to meet individual exercise program goals.

## Introduction

The direct measurement of maximal oxygen uptake ($\dot{V}O_{2max}$) during exercise to exhaustion provides a scientifically rigorous means of comparing the aerobic capacities of different individuals and of assessing the effects of endurance training on cardiorespiratory fitness[1]. However, the complexity and expense of this approach has led to the development of simpler techniques designed to achieve the same ends. After a brief description of a maximal exercise test which can be used to compare the cardiorespiratory fitness of different individuals this paper will discuss in detail how to use the heart rate response to standardized exercise to monitor the effects of endurance training on the relative fitness of an individual.

## Comparing cardiorespiratory fitness of different individuals

The maximum power output achieved during a progressive maximal exercise test on a cycle ergometer provides a accurate and reproducible means of comparing the cardiorespiratory fitness and physical work capacities of different individuals[2-4]. This test can be used to compare males or females who are either young or have been screened for cardiovascular disease (see ref. 4 for guidelines). The test involves pedalling against zero load for 2 minutes and then pedalling at 75 revolutions per minute (RPM) at power outputs which increase by 37.5 watts each minute until the subject is unable to continue or the pedal rate falls below 70 RPM. Either the maximum power output which can be sustained for a full minute or the maximum time to exhaustion provides an accurate and reproducible basis for comparing the maximal physical work capacity of different individuals[2,3]. In contrast, indirect techniques such as the Åstrand-Rhyming nomogram which estimate maximum aerobic capacity ($\dot{V}O_{2max}$) from the submaximal heart rate response to cycle or step test exercise[5,6] (Fig.6) are not accurate enough to permit the valid comparison of different individuals[7]. This is primarily because the relationship of heart rate to oxygen consumption is not necessarily linear at near-maximal power outputs and there is wide variability in maximal heart among individuals (Figs 1,2)[7-9]. Although recent research suggests there are ways of improving the accuracy of this approach[10], currently the most profitable use of the heart rate response to submaximal work is to set the goals and follow the relative progress of endurance exercise programs where the individual can serve as his or her own control[3].

Precribing exercise programs and monitoring changes in relative fitness

The four essential aspects of any endurance conditioning program are the Type, Frequency, Duration, and Intensity of exercise[6-8]. Exercise intensity is the most important factor in determining the response to a training program[8] and can be expressed in either absolute terms such as power production in watts or running speed in meters/sec, or in relative terms such as a percentage of either maximal heart rate or $\dot{V}O_{2max}$. In this paper, exercise intensity refers to a percentage of maximal heart rate.

Exercise prescriptions typically specify the type, duration, and frequency of exercise but provide only a qualitative estimate of the exercise intensity needed for endurance conditioning. For example: bicycle "vigorously" at least 3 times per week for a minimum of 20 minutes per bout excluding warmup/cool-off time[4,7,8]. Although it is easy to set guidelines for exercise duration and frequency, it is much more difficult to specify the exercise intensity needed for a training effect since it varies widely both among and within individuals as a function of fitness[4,7,8].

The Karvonen formula (Training heart rate = Maximal heart rate x Exercise Intensity = (220 - age) x (0.6 to 0.85) provides a rough estimate of the exercise intensity needed to improve aerobic fitness[9] which can be useful at the start of an exercise program. However, maximal heart rate cannot be accurately determined from the formula "220 - age" due to the wide range of maximal heart rate among normal individuals of a given age ($\pm$ 12 beats/min, SD)(Fig. 1)[7,9], and there is no way of assessing whether the qualitatively chosen exercise intensity has the desired effect on fitness.

Using HRstd to monitor changes in aerobic fitness

A simple way of assessing the effects of an exercise program on physical fitness is to periodically measure heart rate at three or more standardized submaximal power outputs. A relative increase in an individual's aerobic fitness will be reflected in decreases in heart rate at specific submaximal power outputs, and vice-versa[7,11](Figs 3,5). An initial workout serves as a point of reference against which subsequent determinations of HRstd or HRref can be compared. If the individual's aerobic fitness increases, the steepness and/or elevation of this line will decrease. If the subject's fitness decreases, HRstd and the steepness and/or elevation of the line relating heart rate to power output will increase (Fig. 3).

The feedback provided by periodic measurements of HRstd permits the duration, frequency and, most importantly, the intensity of exercise to be adjusted to achieve the desired training effect (Fig. 4). This approach allows a gradual, self-paced exercise program. After a number of weeks, depending on the exercise regimen and initial fitness, the subject will adapt to a given level of exercise and no further change in HRstd will occur (Fig. 5).

Practical steps

Choosing a reference exercise

There are two approaches. Heart rate can be measured during exercise on an ergometer where power output can be quantified in watts (standard heart rate, HRstd), or it can be measured during any timed, repeatable exercise (reference heart rate, HRref). The main advantages of knowing heart rate at specific power outputs (HRstd) are that smaller changes in fitness can be detected and that broad estimates of $\dot{V}O_2$ and $\dot{V}O_{2max}$ can be obtained from the Åstrand-Rhyming nomogram (see Fig. 6 for instructions). The heart rate response to submaximal exercise can also be used to estimate exercise energy expenditure in METS (multiples of resting oxygen consumption) by dividing the submaximal $\dot{V}O_2$ (obtained from HRstd and the Åstrand-Rhyming nomogram, Fig. 6) by an estimated resting $\dot{V}O_2$ of approximately 3.5 milliliters/kilogram/minute [4].

Although any type of ergometer can be used to determine HRstd, cycle ergometers are the most common since they are compact, relatively inexpensive and provide a simple way of quantifying power output. Monark and Schwinn make excellent cycle ergometers. If an ergometer is not available, the heart rate response to any timed exercise, such as walking, running, bicycling, or rowing over a given course (HRref) can be used to follow relative changes in aerobic fitness over time. A step test, where platform height (0-50 cm, 0-20 inches) and stepping frequency (12-30/min) can be varied to suit the individual, can also be used as the reproducible form of exercise needed to follow changes in HRref.

Measuring heart rate

Although heart rate can be determined from the carotid artery pulse on either side of the neck just below the hinge of the jaw, a better approach is to measure heart rate during exercise with a simple heart rate monitor. Measuring heart rate during exercise avoids the inaccuracies arising from the rapid and variable decrease in heart rate which occurs immediately after exercise[9]. Not all heart rate monitors work well during exercise. Generally, the most dependable have electrodes from sense the electrical signals from the heart.

It may be difficult to determine heart rate during exercise with an electrocardiogram machine which cannot filter out electrical noise arising from intercostal muscle activity. This interference can be reduced by placing the electrodes over bone rather than muscle, and by vigorously cleaning the electrode site with an alcohol swab.

Using standard heart rates

The numbers in the following section refer to those in Fig. 4.

(1) Decide to initiate an endurance exercise program.

Increased work capacity and other potential benefits of regular exercise might motivate an individual to initiate an exercise program.

(2) Determine the initial heart rate response to three or more standardized power outputs.

After warming up, empirically identify three power outputs which result in heart rate from approximately 60 to 85% of maximum heart rate (heart rate max = 220 - age). During the determination of HRstd or HRref, the ambient temperature should be cool and the stomach empty (1 h after light meal, 3 h or more after a heavy meal). Make a note of the steady-state heart rate towards the end of each 3-5 min period at each power output.

For example, a young adult might warm up for 5-10 minutes at heart rates of 80 to 120, and then cycle at 70 watts for 3-5 minutes and record a heart rate of 95 beats per minute near the end of the period. Without stopping, the process is repeated at power outputs of 110 and 175 watts and corresponding heart rates of 107 and 149 beats per minute are recorded. If careful measurements have been made the points on a plot of heart rate versus power output in watts should fall in a straight line with little scatter.

Although the relationship between submaximal heart rate and running speed is usually linear, the points on a plot of heart rate versus walking speed, rowing speed, etc., may not fall on a straight line. In these cases, a table of the changes in HRref through time can be used to follow changes in aerobic fitness.

(3) <u>The conditioning phase.</u>

Decide on the intensity, duration, frequency, and types of exercises to be used in the endurance conditioning phase of the program. This conditioning phase of the program can involve many different types of exercise as long as they are predominantly aerobic and share common major muscle groups with the type of exercise used in the periodic measurement of HRstd or HRref.

(4,5) <u>Assess the adaptive response of the cardiorespiratory system through the periodic remeasurement of HRstd.</u>

This can be done at intervals of 2 or more weeks depending on the subject's initial level of fitness and the strenuousness of the exercise program.

(6,7) <u>Compare the results to the initial HRstd determination</u>.

Improvements in HRstd can help sustain interest in a program of regular exercise.

(8) <u>Adjust the intensity, duration and frequency of the exercise protocol as needed to meet the goals of the exercise program.</u>

The goal of the program could be to maintain a given level of fitness, achieve a 5 percent increase in estimated $\dot{V}O_{2max}$, or reach the 2000 kcal/week exercise energy expenditure needed to maintain a healthy cardiovascular system[11]. The simple guide of 5.0, 7.5, and 10.0 Kcal/min for light, mixed, or vigorous exercise, respectively, can be used to estimate exercise energy expenditure[12]. For more information on energy expenditure during different types of activities, see reference 7.

## Precautions

The likelihood of injury and abnormal electrical activity by the heart is reduced when exercise is preceded by a warm-up period[13]. In addition, cooling off after exercise reduces the likelihood of fainting or sore muscles by allowing time for circulatory redistribution and the removal of metabolic acids from the muscles.

Any exercise program should be instituted gradually. Individuals with heart/lung disease, gross obesity, diabetes or other pathophysiological problems should consult with their doctors before starting a exercise program. In this regard, consult the American College of Sportsmedicine Guidelines for Graded Exercise Testing and Exercise Prescription[4].

## Conclusions

The feedback provided by periodic determination of standard heart rates, i.e. heart rates at standardized submaximal exercise intensities, solves the central problem of defining the intensity required for an individual to increase aerobic fitness. Although a maximal exercise test is needed for an accurate comparison of the absolute physical work capacity of one individual with another, a submaximal test can be used to reliably assess relative changes in individual endurance capacity during the course of an exercise program.

References

1. Clausen JP: Effects of physical training on cardiovascular adjustments to exercise in man. Physiol Rev 1977;57:779-816

2. Patton JF, Vogel JA, Mello RP: Evaluation of a maximal predictive cycle ergometer test of aerobic power. Eur J Appl Physiol 1982;49:131-140

3. Myles WS, Toft RJ: A cycle ergometer test of maximal aerobic power. Eur J Appl Physiol 1982;49:121-129

4. American College of Sports Medicine. Guidelines for Graded Exercise Testing and Exercise Prescription. Philadelphia, Lea and Febiger, 1980

5. Astrand P-O, Rhyming I: A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work. J Appl Physiol 1954;7:218-221

6. Margaria R, Aghemo P, Rovelli E: Indirect determination of maximal $0_2$ consumption in man. J Appl Physiol 1965;20:1070-1073

7. Astrand PO, Rodahl K: Textbook of Work Physiology, Physiological Bases of Exercise, New York City, McGraw-Hill Book Co, 3nd Ed, 1986

8. Kasch, FW: The validity of the Åstrand and Sjostrand submaximal tests. The Physician and Sportsmedicine 1984;12:47-52

9. Davies, CTM: Limitations to the prediction of maximal oxygen intake from cardiac frequency measurements. J Appl Physiol 1968; 24:700-706

7. Pollock, ML: The quantification of endurance training programs. Exer Sports Sci Rev 1973;1:155-188

8. Shephard, RJ: Intensity, duration and frequency of exercise as determinants of the response to a training regimen. Int Z angew Physiol 1968;28:272-278

9. Karvonen MJ, Kentala E, Mustala O: The effects of training on heart rate. A "longitudinal" study. Ann Med Exp Biol Fenn 1957;35:307-315

10. Legge BJ, Banister EW: The Astrand nomogram revisited. J Appl Physiol 1986;61:1203-1209

11. Kappagoda CT, Linden RJ, Newell JP: Effect of the Canadian air force training programme on a submaximal exercise test. Quart J Expt Physiol 1979;64:185-204

12. Paffenbarger RS, Hyde RT, Wing AL, et al: Physical activity, all-cause mortality, and longevity in college alumni. N Engl J Med 1986;314:605-613

13. Barnard RJ, Gardner GW, Diaco NV, et al: Cardiovascular responses to sudden strenuous exercise - heart rate, blood pressure and ECG. J Appl Physiol 1973;34:833-837

## Figure Legends

Fig. 1 In both males and females there is a progressive decrease in heart rate during maximal exercise with age. However, there is wide range in maximal heart rate at a given age as shown by the dashed lines denoting $\pm$ 1 standard deviation (SD). This variability among subjects makes a significant contribution to the inaccuracy of maximum oxygen uptake estimated by extrapolation from the submaximal heart rate and oxygen consumption relationship.

Fig. 2 The increase in heart rate with increasing work load and oxygen uptake is linear over a wide range. However, in some subjects oxygen uptake may increase relatively more than heart rate at high power outputs. The prediction of maximal oxygen uptake by an extrapolation to the subject's presumed maximal heart rate (195 in this case) suggests a maximum of 2.9 liters per minute (dashed line), but the actual maximal aerobic capacity is 3.2 liters per minute (solid line).

Fig. 3 When an individual becomes more fit, the line relating heart rate to power output during submaximal exercise will become less steep and at a lower elevation, i.e. there will be a lower heart rate at a given power output. If an individual becomes less fit, the straight line relating submaximal heart rate and power output will become more steep and at a higher elevation.

<u>Fig. 4</u> This feed back loop illustrates how the periodic determination of heart rate at standard power outputs provides the information needed to adjust an individual's exercise program to meet desired goals (see the text for a detailed discussion).

<u>Fig. 5</u> Heart rate at two fixed workloads decreased during the course of 3 1/2 months training.

<u>Fig. 6</u> The Åstrand-Rhyming nomogram can be used to estimate both submaximal oxygen uptake and maximal oxygen uptake in males or females. The first step is to estimate submaximal oxygen uptake at a given power output by reading horizontally from the male or female 'work load' scale to the '$\dot{V}0_2$, liters' scale. Next, connect the point on the '$\dot{V}0_2$, liters' scale to the corresponding point on the male or female 'pulse rate' scale on the far left. Finally, read the predicted maximal oxygen uptake from the 'max. $\dot{V}0_2$, liters per minute' scale in the middle. For example, a female subject who reaches a heart rate of 156 while cycling at 100 watts has a submaximal $\dot{V}0_2$ of approximately 1.48 liters per minute and a predicted 'max. $\dot{V}0_2$' of approximately 2.3 liters per minute (– – –). A male subject who reaches a heart rate of 166 while cycling at a power output of 200 watts has a submaximal $\dot{V}0_2$ of approximately 2.83 liters per minute and a predicted 'max. $\dot{V}0_2$' of 3.6 liters per minute (——). The estimates of $\dot{V}0_{2max}$ can be corrected for differences in the age-predicted or directly measured maximum heart rate (Table 1).

**(Figures 1,2,5,6 are modified from Åstrand PO, Rodahl K: <u>Textbook of Work Physiology, Physiological Bases of Exercise</u>, New York City, McGraw-Hill Book Co, 3nd Ed, 1986. Permission from the publisher to use these modified figures has been requested.)**

Fig 1

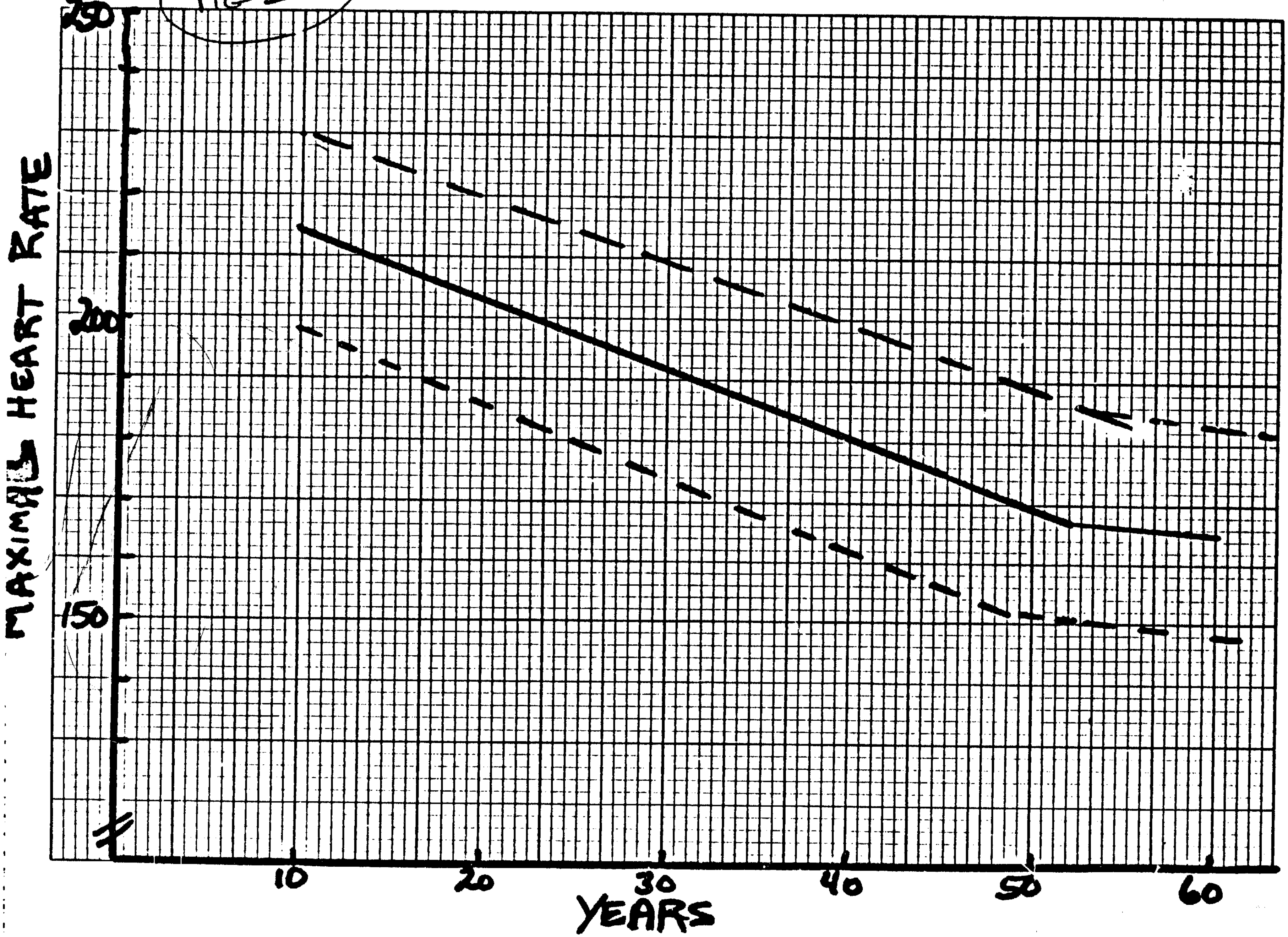

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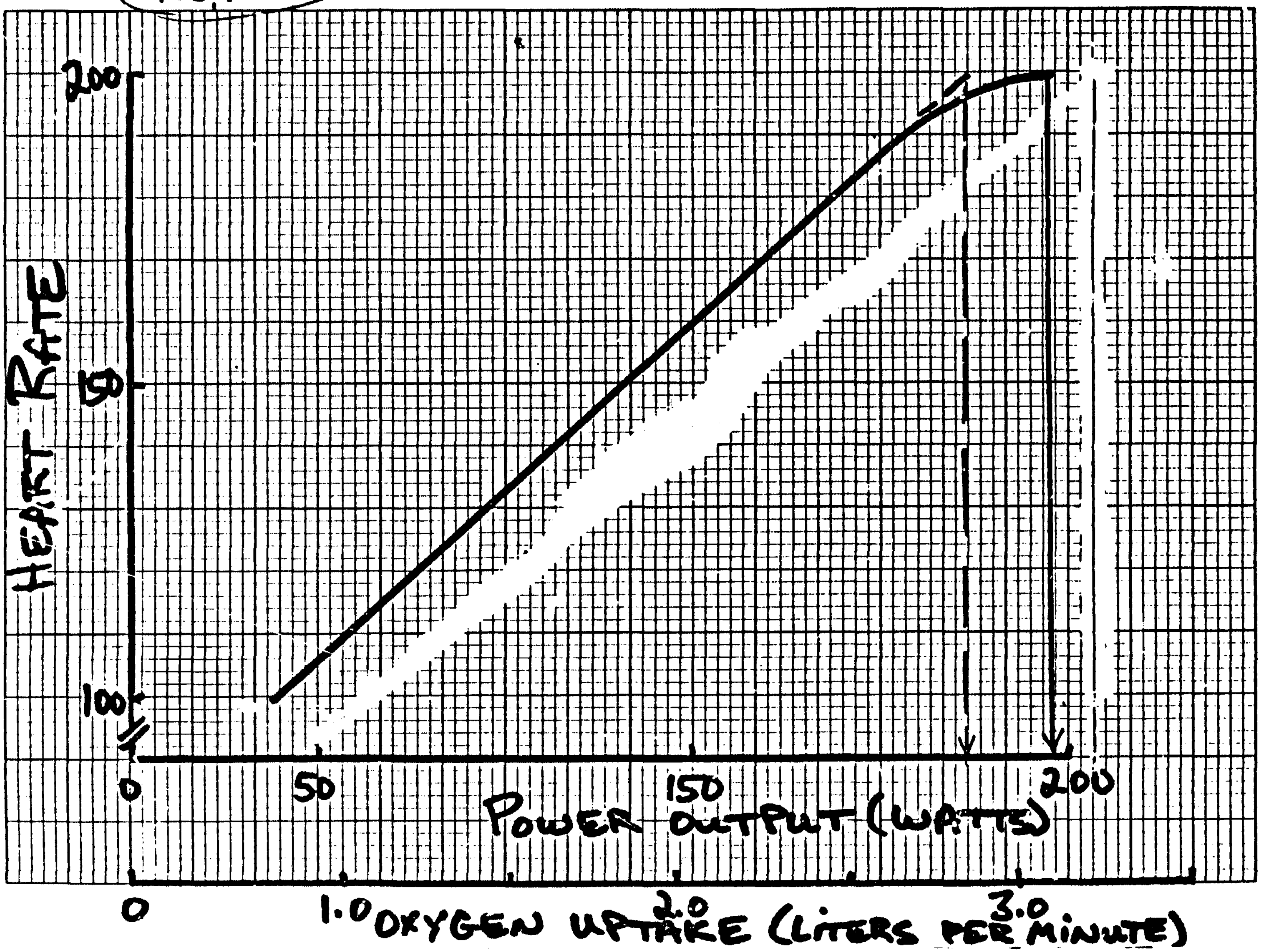
FIG. 2



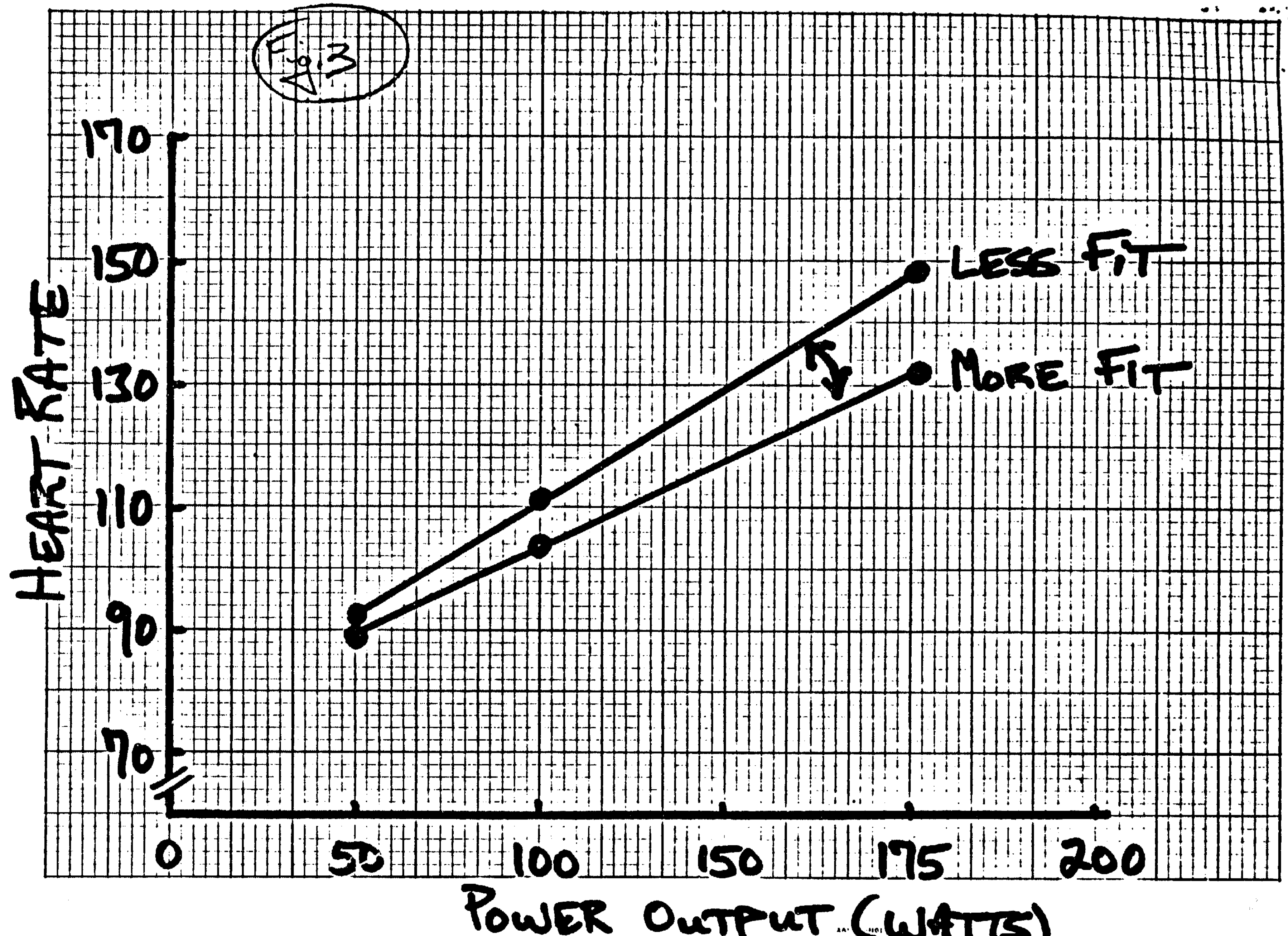


Fig. 3
HEART RATE
170
150
130
110
90
70
0
50
100
150
175
200
POWER OUTPUT (WATTS)
LESS FIT
MORE FIT

Fig. 4'

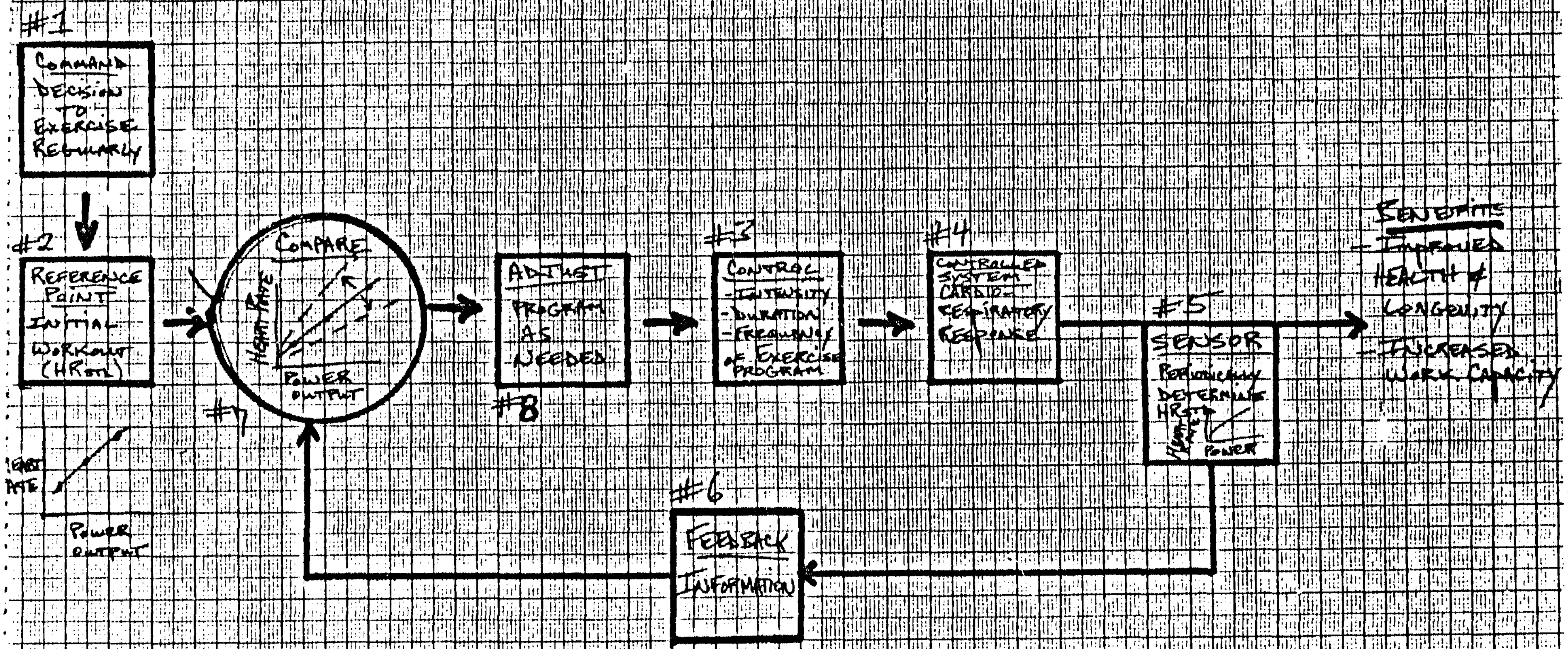

#1
COMMAND
DECISION TO EXERCISE REGULARLY
#2
REFERENCE POINT
INITIAL WORKOUT (HRstl)
HEART RATE
POWER OUTPUT
#7
COMPARE
HEART RATE
POWER OUTPUT
#8
ADJUST
PROGRAM AS NEEDED
#3
CONTROL
- INTENSITY
- DURATION
- FREQUENCY
OF EXERCISE PROGRAM
#4
CONTROLLED SYSTEM
CARDIO-RESPIRATORY RESPONSE
#5
SENSOR
PERIODICALLY DETERMINE HRstl
POWER
#6
FEEDBACK
INFORMATION
BENEFITS
- IMPROVED HEALTH &
LONGEVITY
- INCREASED WORK CAPACITY

Fig. 5

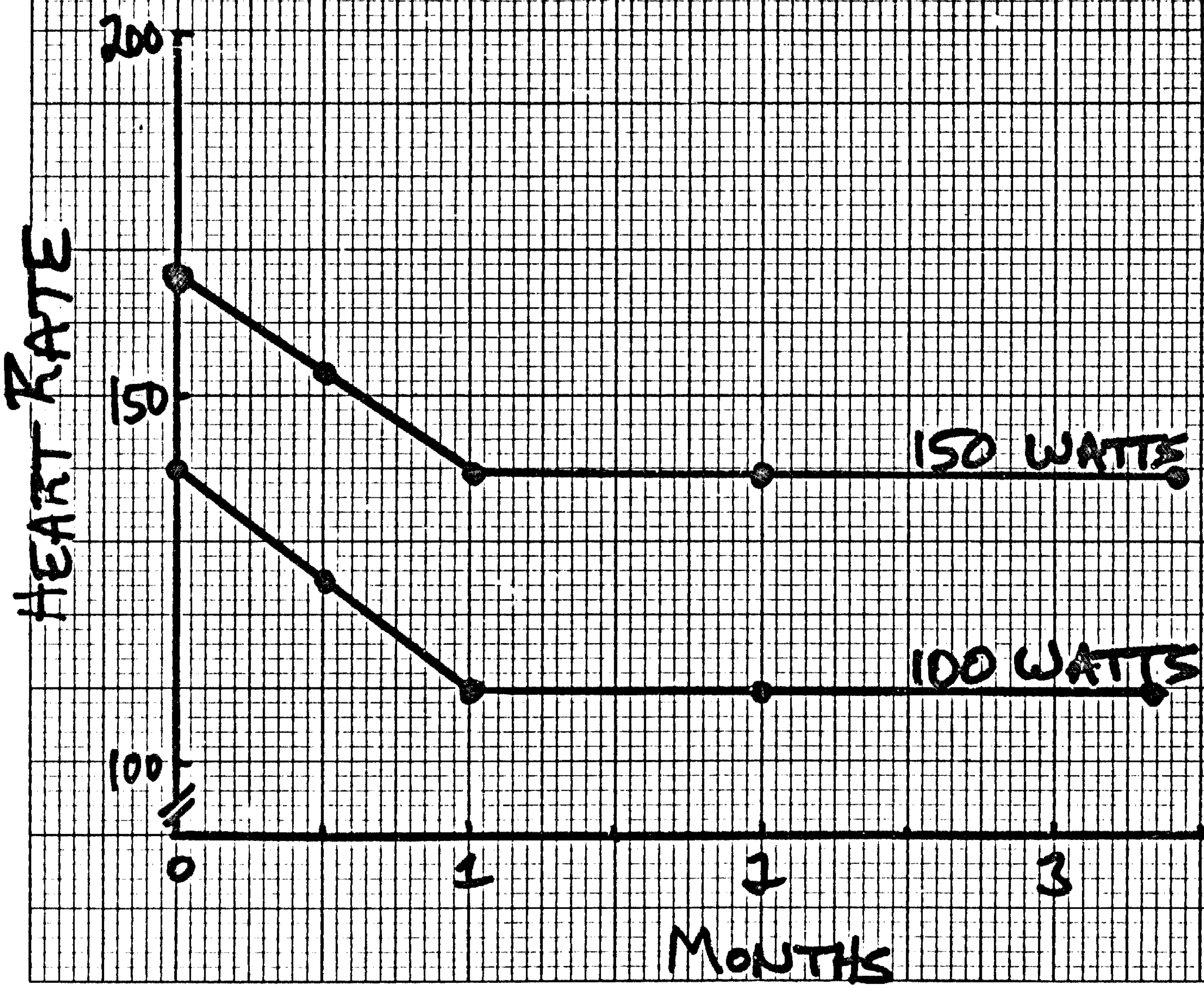
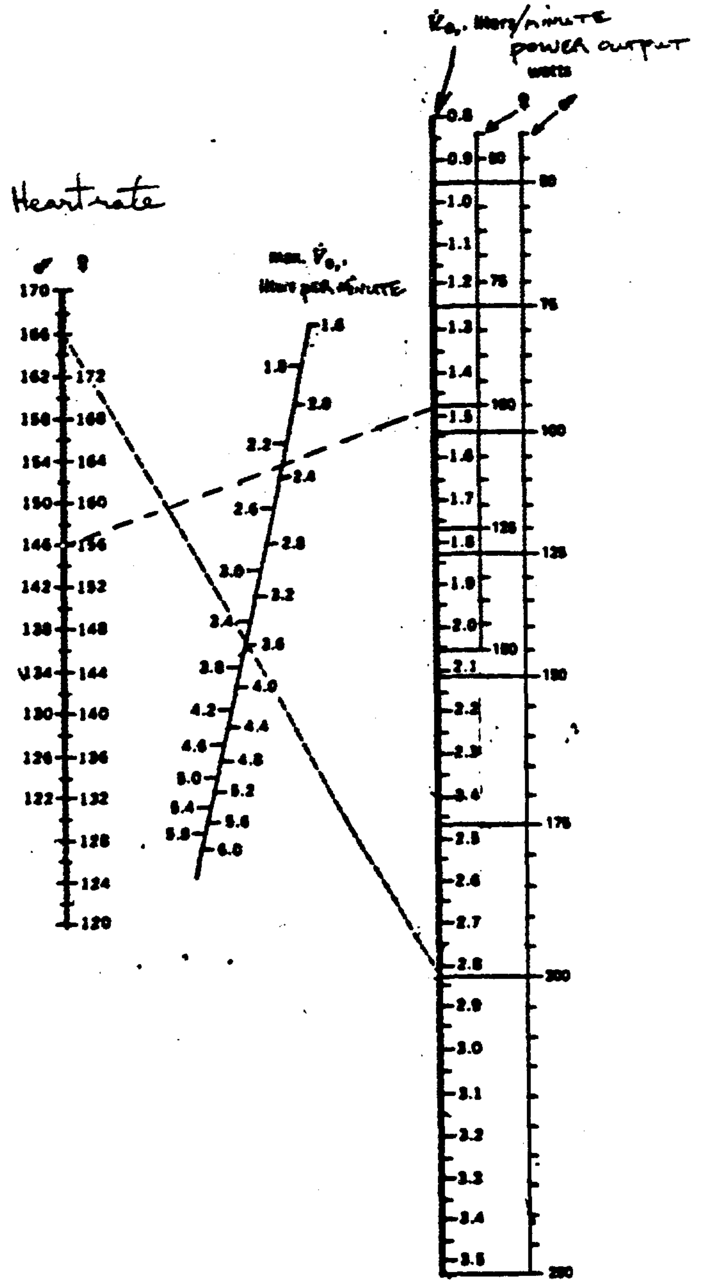


Fig. 6




**Factor to be used for correction of predicted maximal oxygen uptake (1) when the subject is over thirty to thirty-five years of age or (2) when the subject's maximal heart rate is known. The actual factor should be multiplied by the value that is obtained from the nomogram.**

| Age | Factor | Max heart rate | Factor |
|---|---|---|---|
| 15 | 1.10 | 210 | 1.12 |
| 25 | 1.00 | 200 | 1.00 |
| 35 | 0.87 | 190 | 0.93 |
| 40 | 0.83 | 180 | 0.83 |
| 45 | 0.78 | 170 | 0.75 |
| 50 | 0.75 | 160 | 0.69 |
| 55 | 0.71 | 150 | 0.64 |
| 60 | 0.68 | | |
| 65 | 0.65 | | |